OHIO UNIVERSITY

School of Electrical Engineering & Computer Science

Channel Characterization in the 5 GHz Microwave Landing System Extension Band for Future Airport Surface Communications

ICNS Conference

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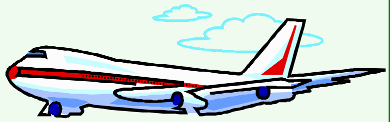
Outline



- Introduction
  - Motivation
  - Band selection
  - Importance of channel characterization
- Measurement coordination
- Regulatory issues
- Channel characterization overview
  - Method
  - Sounding measurements
  - Example results
- Summary & future work

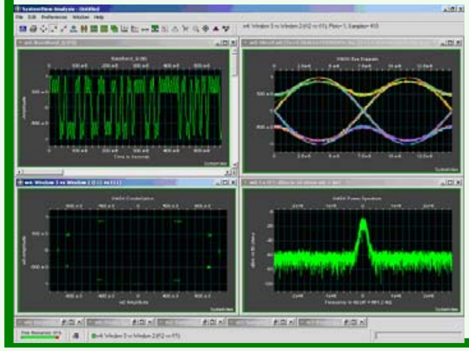
Introduction

- Motivation
  - Civilian aviation anticipates both a near and long-term need for new communications capabilities
    - VHF spectral congestion
    - New services desired
- Band selection
  - Easiest to quickly deploy system in “clean” spectrum
  - Deployment of new systems to “protect” reserved aeronautical spectrum
  - Both these points apply to the MLS extension band, 5.091-5.15 GHz, which is not widely used in many regions

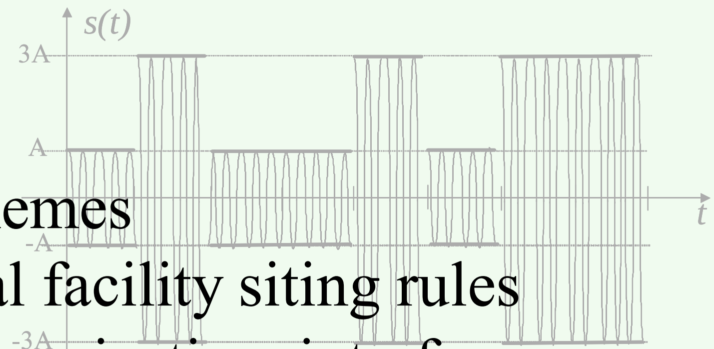
Introduction (2)

- Importance of channel characterization
  - Simply: if you don't know your channel, your system performance will be suboptimal, possibly very poor, with
    - an irreducible channel error rate that can preclude reliable message transfer
    - spatial coverage "holes" where communication is not possible
    - severely limited data carrying capacity

    which would require costly system additions to circumvent
  - Very little work done for MLS band channel
    - Zero wideband experimental work in this band around airport surfaces



Introduction (3)



- Channel characteristics affect
  - modulation(s)
  - forward error correction coding schemes
  - antenna characteristics, and physical facility siting rules
  - receiver processing methods (synchronization, interference suppression, combining, etc., all generally adaptive)
  - power spectrum and bandwidths
  - attainable data rates and latencies, message block sizes
  - adaptation algorithms for allocating resources in T/F/S domains
  - authentication and user ingress/egress latencies
  - duplexing and multiplexing methods
  - security measures and performance (against eavesdropping, jamming, spoofing, etc.)

Measurement Coordination

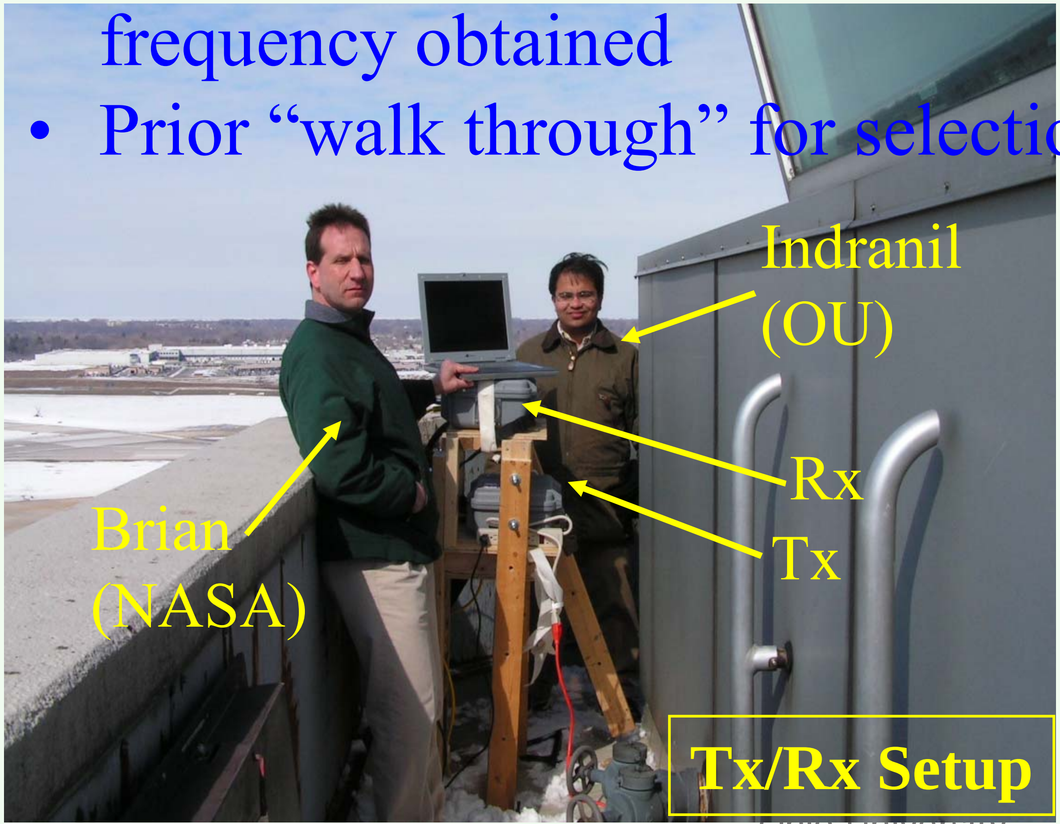
- Cleveland Hopkins Airport (CLE) is one of the 50th busiest airports in the United States
- To gain access to the airport surface area, strict security procedures must be followed—requires careful coordination with airport management
- Airport movement area is a dynamic environment in which airline ramp activities such as baggage, fueling, and catering take place throughout the day
- Also, aircraft are taxiing, pushing and pulling out of gates, while airport security vehicles and others are moving about

Measurement Coordination (2)

- In post 9/11 era, access to airport movement area has become even more complicated -- increased security. The principle objective when planning a measurement activity is to minimize the impact to airport operations.

Measurement Coordination (3)

- Prior to any measurements, an RFI study was conducted by the FAA Spectrum Office (clean!)
- Special Temporary Authorization to transmit at the test frequency obtained
- Prior "walk through" for selection of Tx location

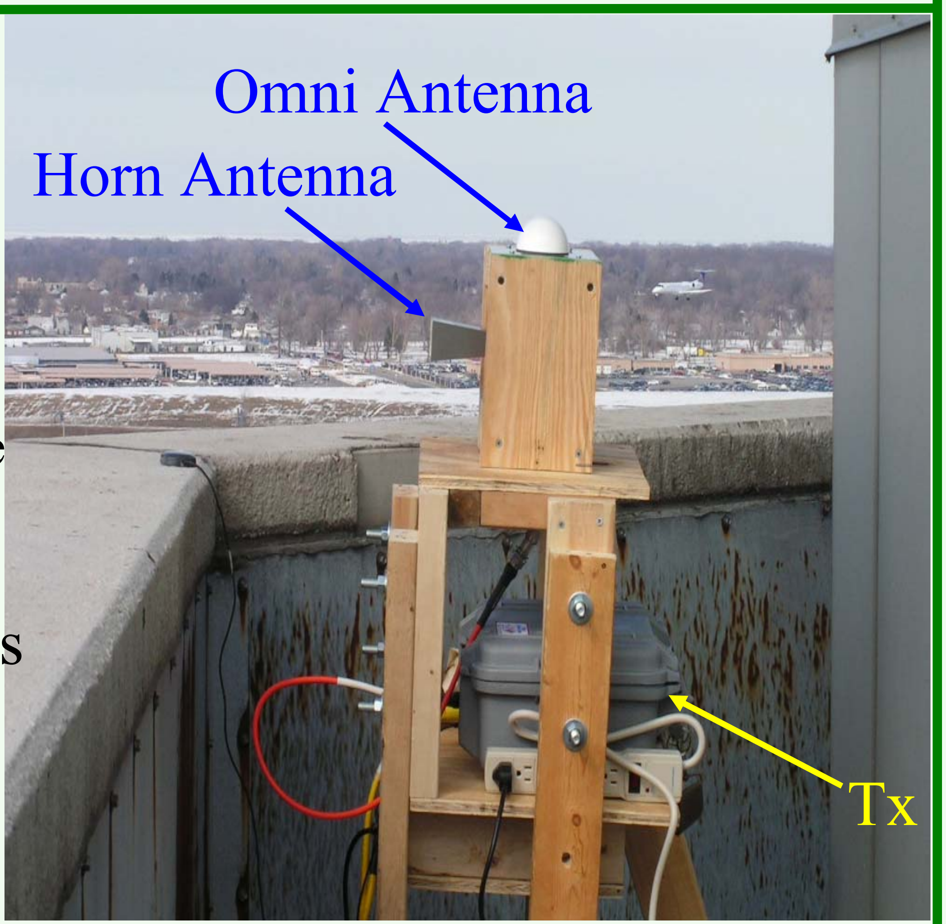


Selected "cat walk" at ATCT sub-junction level for Tx

- Good field of view
- Access to AC power

Measurement Coordination (4)

- Initial measurement plan developed, identified
  - Data recording locations
  - Procedural approach
  - Airport ingress and egress requirements
  - # personnel required to complete measurements
  - Driving procedures
- Desired measurement locations evaluated with FAA for accessibility, time of day, aircraft traffic activity and measurement execution
- Final measurement plan evaluated and approved by FAA



Measurement Coordination (5)

- CLE aerial view, with numbered measurement locations

- Covered
  - Runways
  - Taxiways
  - Gates
  - Cargo areas
  - FAA bldg
  - Access roads
- Both LOS and NLOS sites

Regulatory Issues

- Through industry support functions such as I-CNS 2004, ACAST 2004, NASA has identified protection of the 5000-5150 MHz band for aviation use as one of the top priorities for ACAST
  - Emphasis on the MLS extension band 5091-5150 MHz
    - First, GPS navigation and WAAS/LAAS enhancements circumventing need for MLS deployments, leaving much of the MLS band either quiet or underutilized
    - Second, spectrum at 5 GHz presents enormous potential for revenue to short range, wideband wireless networking OEMs (e.g., 802.11)
    - Third, spectrum auctions in or near this band present potential revenue streams for the federal government
  - Combination of these factors has heightened need to justify the continued use of this spectrum for aviation purposes

Regulatory Issues (2)

- It is NASA's intent to demonstrate, through ACAST, the applicability of this band for wideband surface area signaling, and how this usage may alleviate some of the congested VHF voice bands for ATC
- The first step in this effort is proper characterization of the MLS radio channel
- Radio Communication group of the International Telecommunication Union (ITU-R) holds a World Radio Conference (WRC) every 3-4 years
  - Member nations discuss and decide upon the global use of radio spectrum at these conferences

Regulatory Issues (3)

- On agenda of WRC-2007 is use of aviation spectrum:

  "To consider allocations for the aeronautical mobile (R) service in parts of the bands between 108 MHz to 6 GHz, and to study current frequency allocations that will support the modernization of civil aviation telecommunication systems."

- This agenda item affords opportunity to have areas of spectrum between 108 MHz to 6 GHz characterized for aeronautical mobile route services (AM(R)S)
  - Results of channel characterization being presented to domestic and international governing bodies so that there is a sound engineering argument for use of this band for wideband signaling on the airport surface, and that this band may be included in regards to Agenda Item 1.6. It is intended that this effort support inclusion of MLS band as an integral piece of modernization of civil aviation communication systems

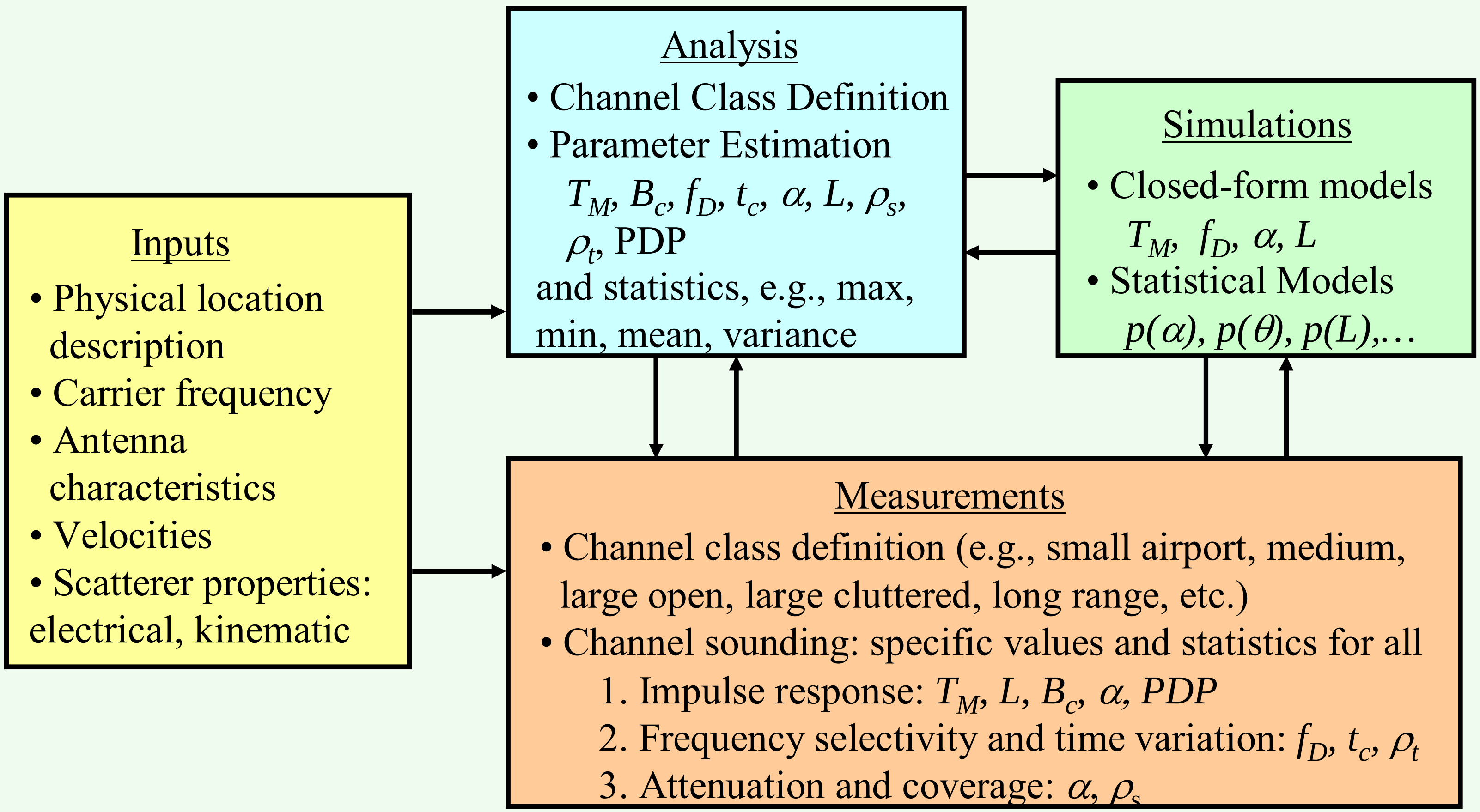
Channel Characterization Overview

- Thorough and accurate channel characterization requires combination of 3 inter-related components:
  - *Analysis*: validate against theory, guide measurements
  - *Simulations*: create models for consistent evaluation of comparative system designs
  - *Measurements*: data to build models, affirm theory, help classify, and identify unforeseen conditions
- Analytical and measurement results we obtain will be directly usable by engineers evaluating and/or designing communication systems for this application

$$h(\tau;t) = \sum_{k=0}^{N-1} \alpha_k(t) \exp\{ j[\omega_{D,k}(t-\tau_k(t)) - \omega_c(t)\tau_k(t)\} \delta[t-\tau_k(t)]$$

Channel Characterization Plan

- Today's focus on measurements and analysis

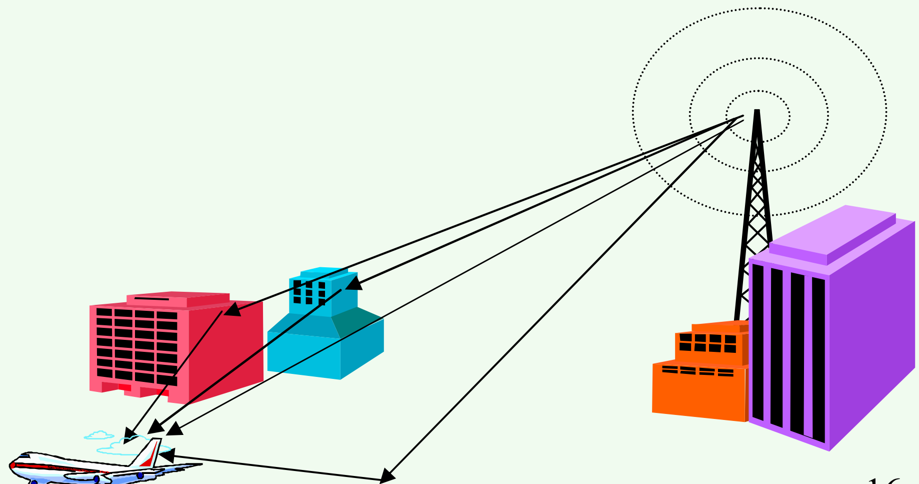


Channel Characterization Method

- By channel "sounding," we mean transmission and subsequent reception of a test signal, from which we can infer channel characteristics: the impulse response
- Common test signal is a spread spectrum (direct sequence) signal, whose known correlation properties can be exploited to estimate channel's impulse response

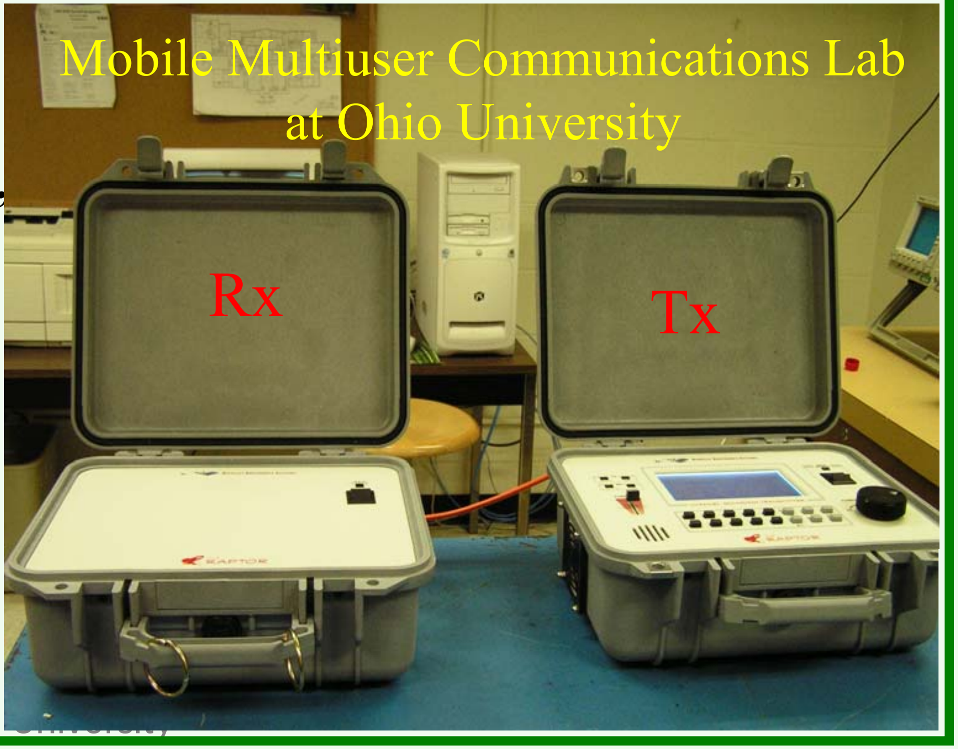
What is the channel?

A wireless channel is the (set of) transmission path(s) taken by an electromagnetic signal from transmitter to receiver. The mobile channel is the wireless channel with at least one platform (Tx or Rx) in motion.



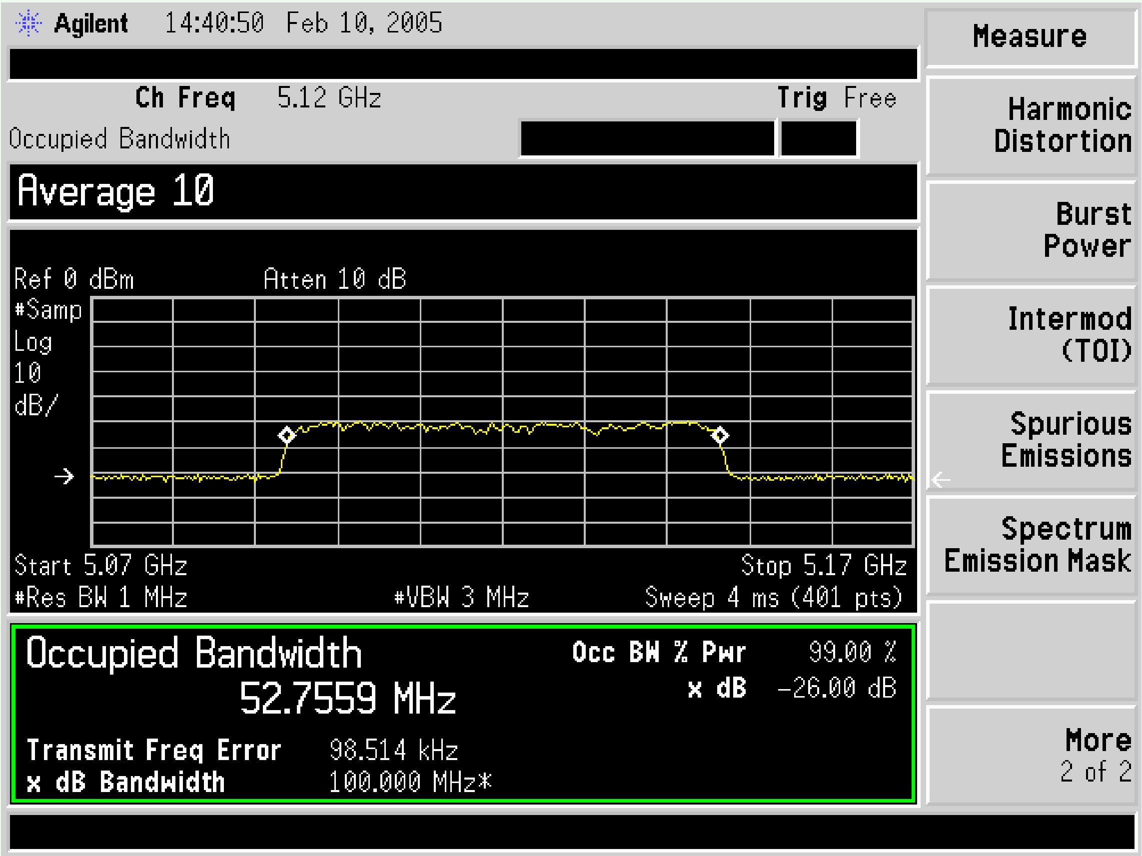
Channel Sounder

- For sounding, we have purchased and employed a wideband channel sounder with adjustable center frequency, transmit power, and bandwidth
  - Modified version of Berkeley Varitronics Inc. “Raptor” model, for which we have obtained several upgrades, including a faster data output rate and increased output power
  - Multiple antenna types



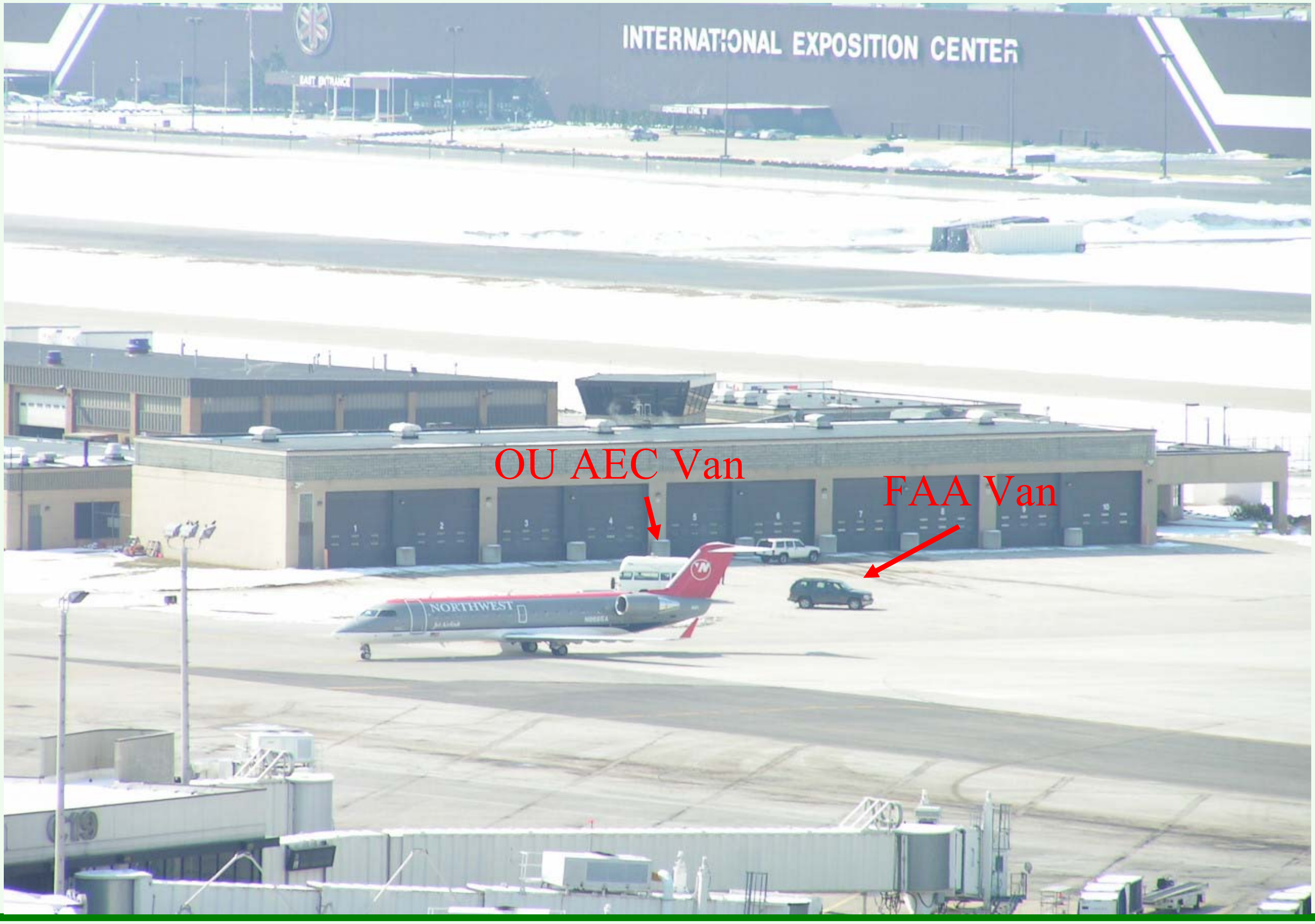
Channel Sounder (2)

- Transmitted signal measured power spectrum



- Chip rate 50 Mcps
- f_c=5.12 GHz
- Span=100 MHz
- 99% power BW equal to 52.76 MHz

Measurements: Example Photos (1)

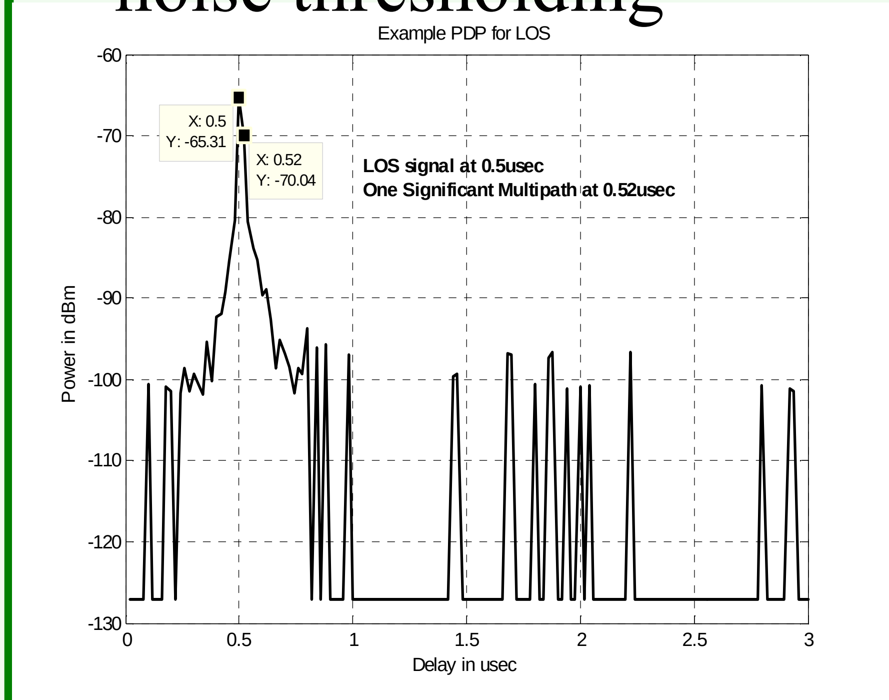


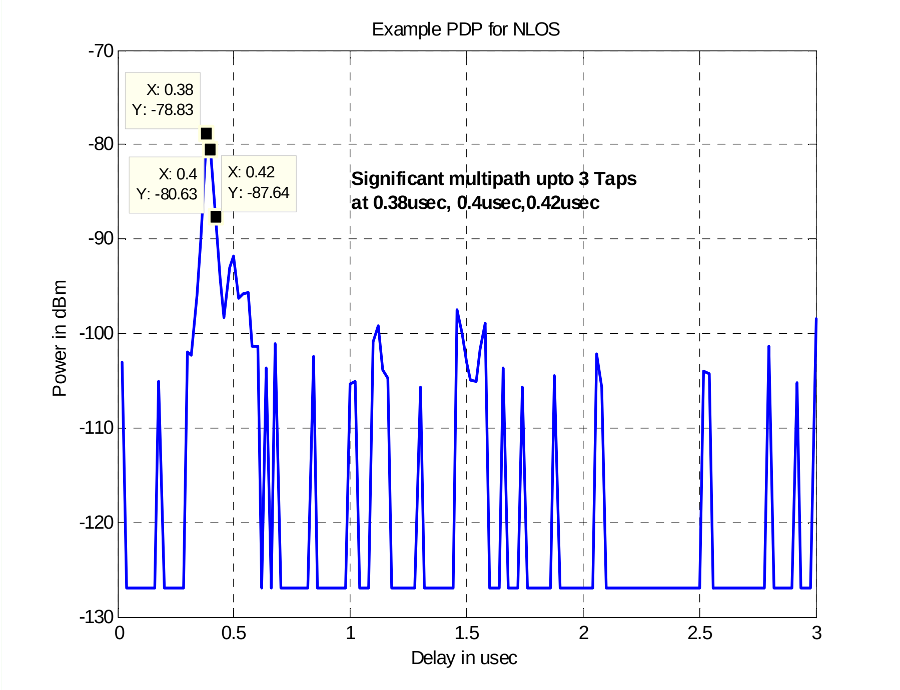
Measurements: Example Photos (2)

Measurements: Example Photos (3)

Example Results

- Power delay profiles (received power vs. delay), after noise thresholding





LOS case

Direct signal at 0.5 μsec

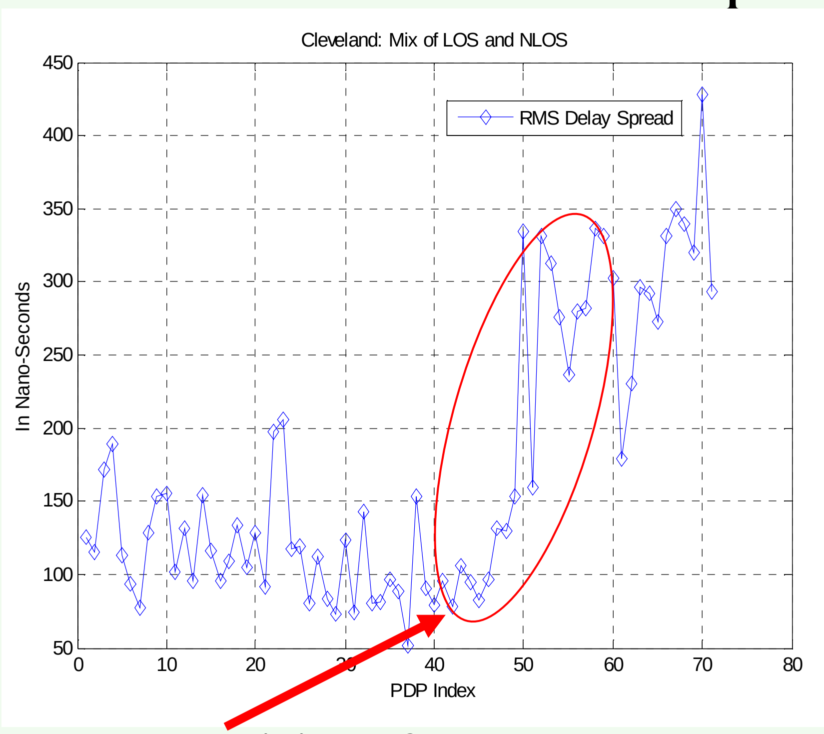
Multipath (-5 dB) at 0.52 μsec

NLOS case

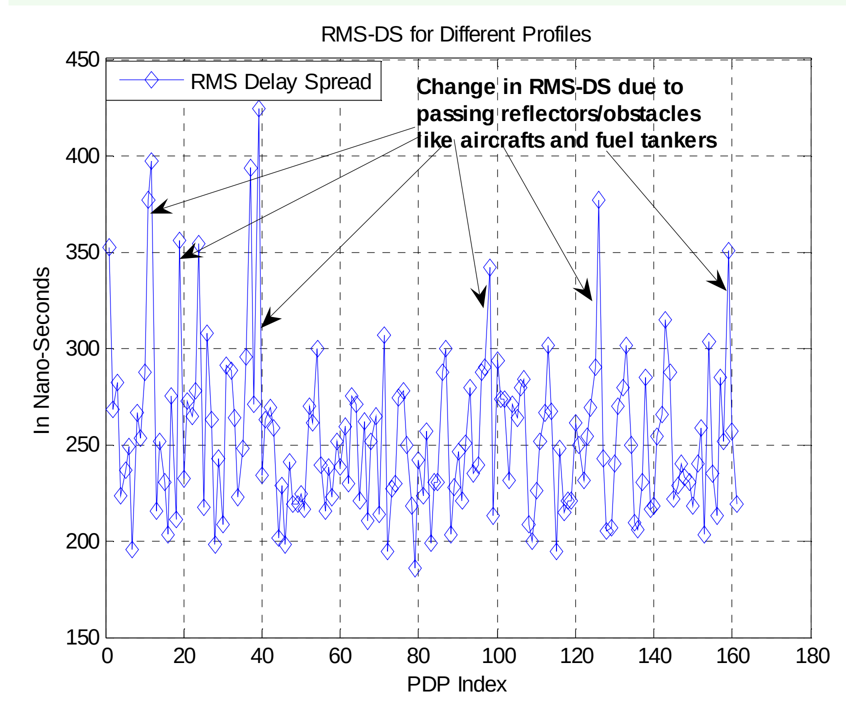
Significant multipath (~ 9 dB) up to $2T_c$ (0.04 μsec)

Example Results (2)

- Useful statistic is RMS delay spread (DS)
- Plots of RMS-DS vs. profile index



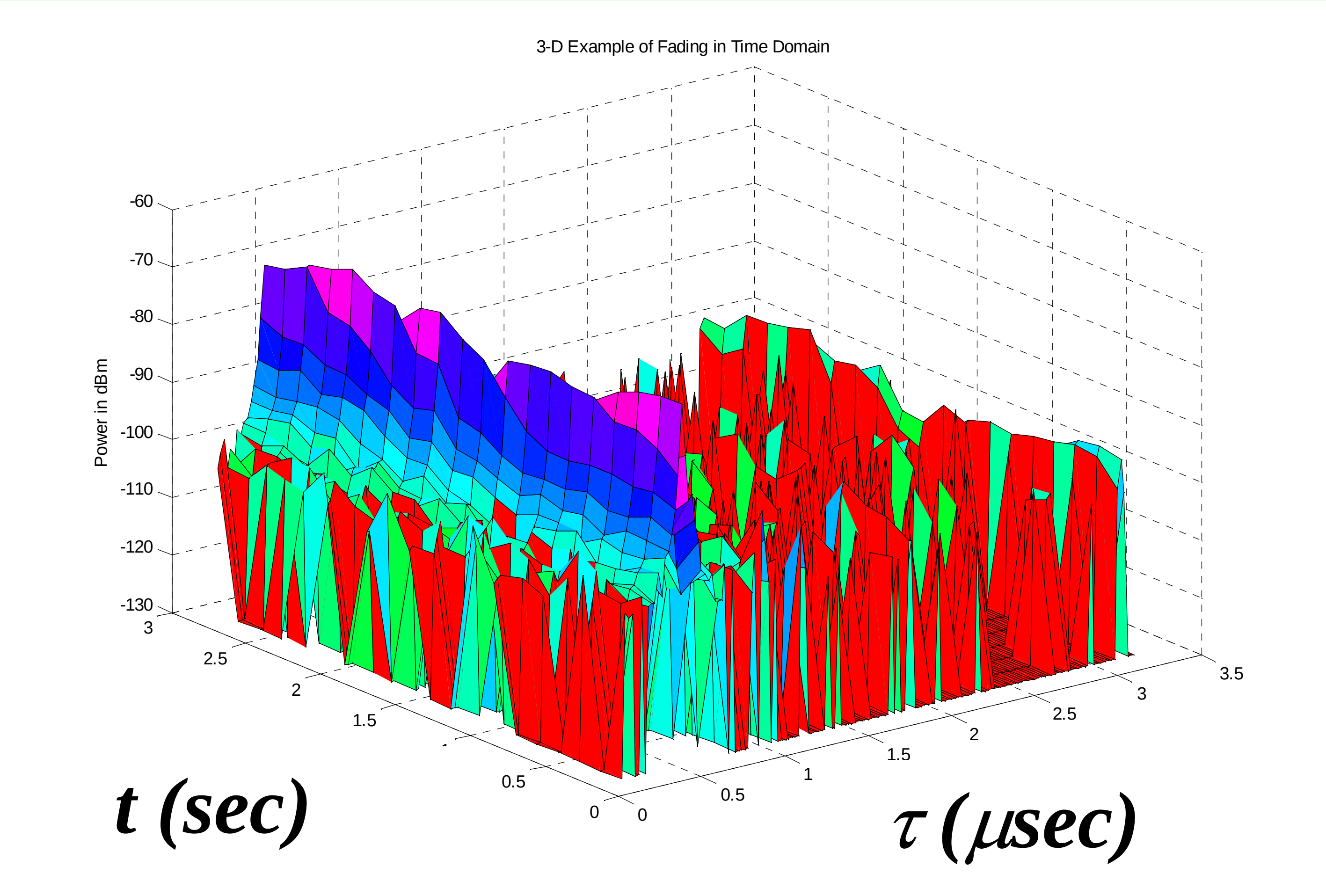
Transition from LOS to NLOS



Variation in RMS-DS due to Scattering

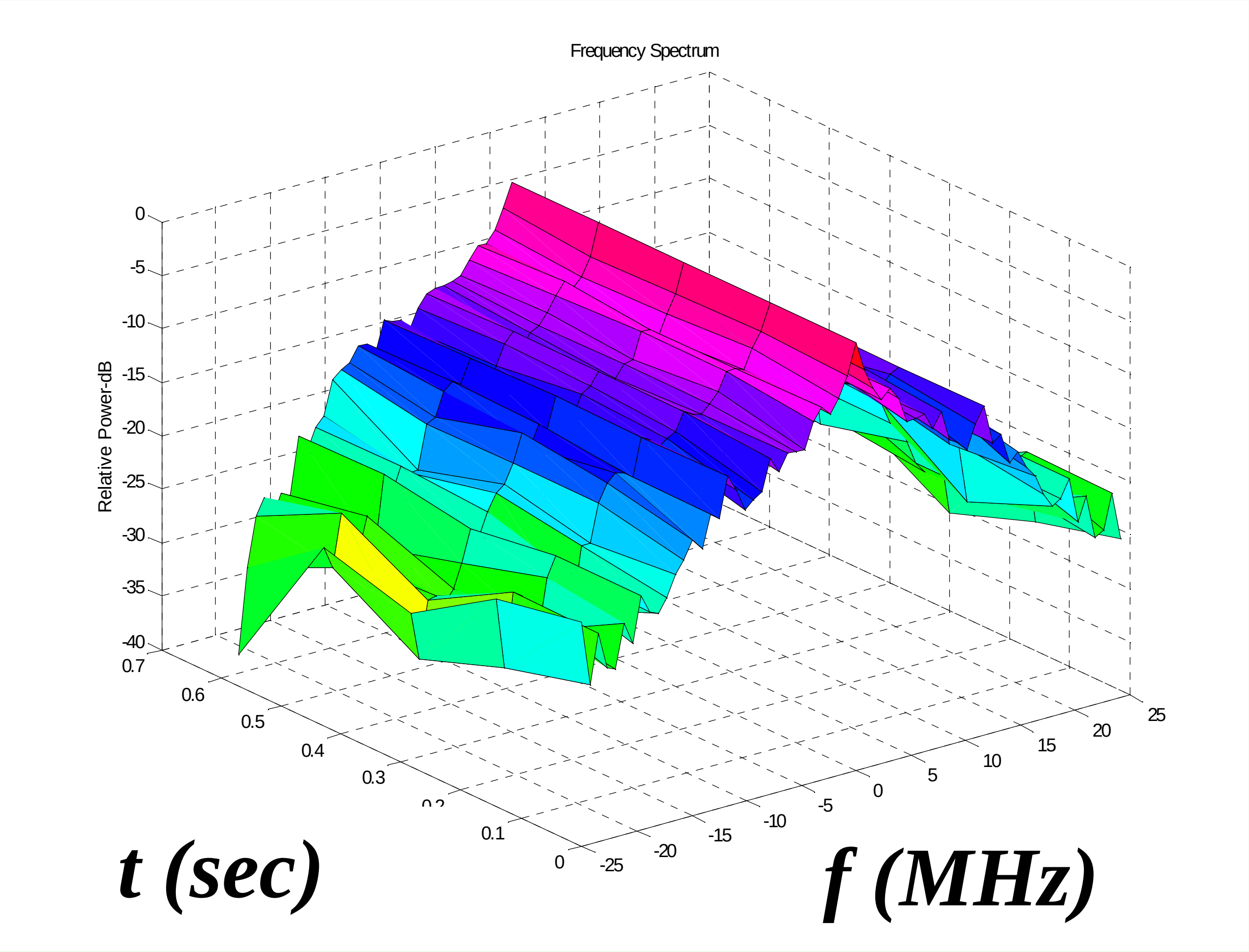
Example Results (3)

- PDP: power vs. delay and vs. time



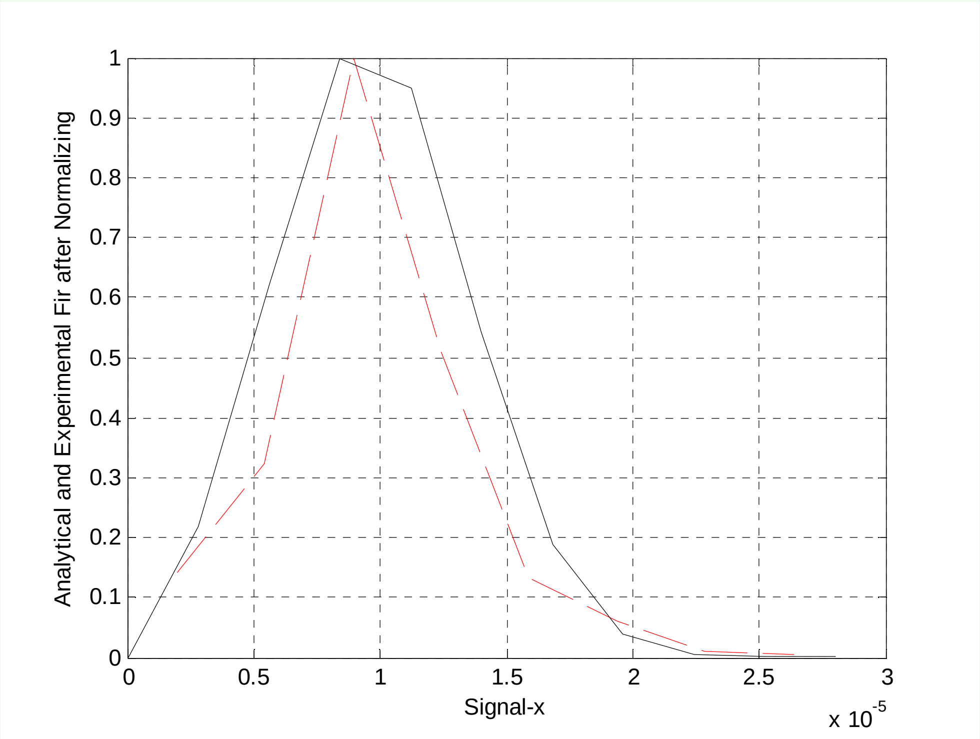
Example Results (4)

- Time-varying spectrum $|H(f,t)|^2$



Example Modeling Result

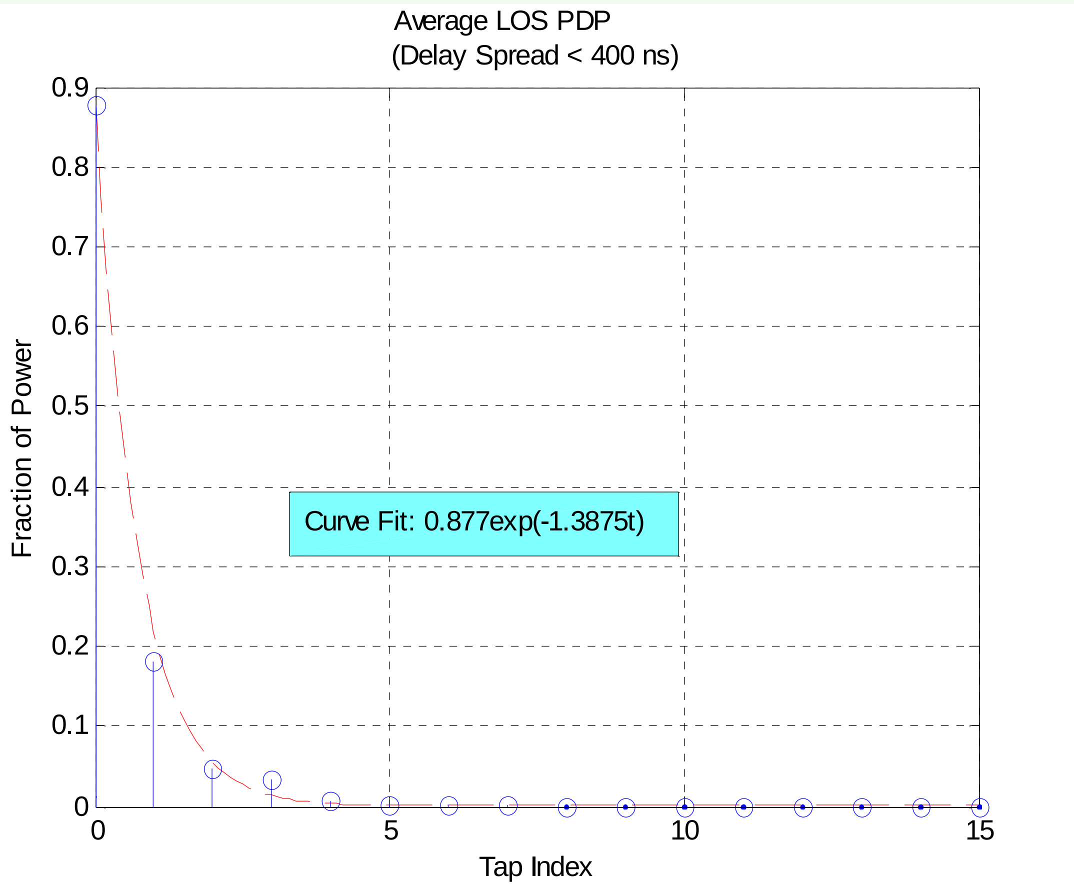
- Amplitude distribution, LOS case



- Fit to Ricean pdf
- "Rice factor" $K \cong 2$ dB

Example Modeling Result (2)

- Curve fit for power delay profiles for LOS, Open Areas



- Channel has non-neglible power in 4 “taps,” spaced T_c seconds apart

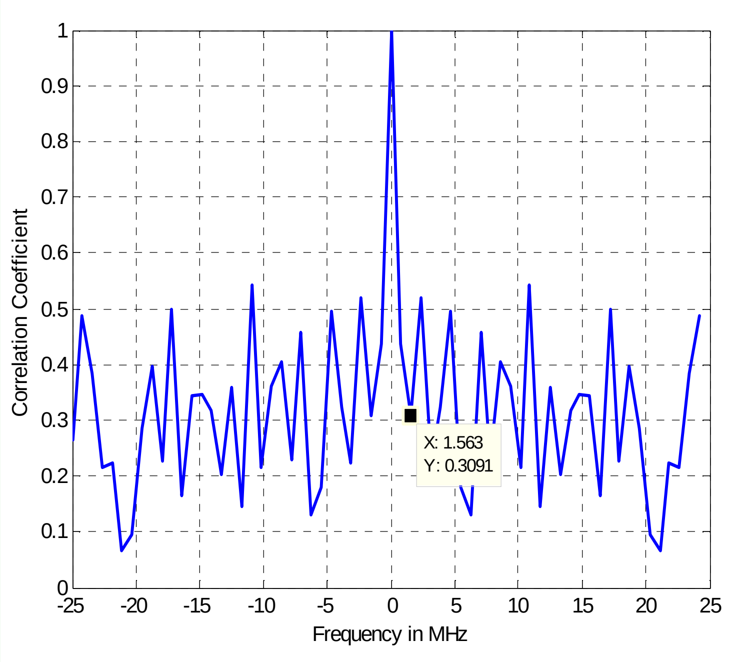
Some Summary Channel Statistics

Statistics for RMS-DS and Coherence Bandwidth for CLE Airport

Statistic	LOSO		MR	
	σ_τ (nsec)	$BW_c = 1/\sigma_\tau$ (MHz)	σ_τ (nsec)	$BW_c = 1/\sigma_\tau$ (MHz)
Max σ_τ	395	2.5	2306	0.433
Min σ_τ	49.5	20.2	401	2.5
Mean σ_τ	311	3.2	763	1.3

LOSO = LOS Open
MR = Mixed Region

Example FCE, Mixed LOS and NLOS Case (Points 25-26)



Summary & Conclusions

- Described characterization of the 5 GHz MLS “extension” band channel from various perspectives
- First discussed need for such an effort from the point of view of efficient communication link design
- Recent measurement campaign at the Cleveland Hopkins Airport also described, including
  - Coordination with local authorities required for the successful tests
  - Short description of the measurement process
- Significance of effort from perspective of regulatory constraints and protection of this band for aviation use also discussed

Future Work

- Gathering additional measurement data at several large airports
- Subsequent data processing and channel modeling required to complete the foundation for future airport surface area wireless communication system development